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Validation of the spectral mismatch correction factor using an LED-based solar simulator

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***Abstract* — LED-based solar simulators are gaining popularity in the PV characterization field. There are several reasons for this trend, but the primary interest is often the potential of tuning the light source spectrum to a closer match to the AM 1.5G reference spectrum than traditional Xenon or metal-halide light sources provide. In this work we will use an EcoSun10L LED module tester from Ecoprogetti to perform short circuit current (I_{SC}) measurements under various class A, B and C spectra. We will apply a spectral mismatch correction to the measured I_{SC} under each test spectrum per IEC 60904-7. In all scenarios, a small area mono-Si cell is used the reference cell and a similar mono-Si cell is used as the PV device under test (DUT). Finally, we quantify the variation of the DUT's measured and spectrally corrected I_{sc} under the class A, B and C test spectra.**

I. Introduction

Characterization of photovoltaic (PV) devices at standard test conditions (STC) assumes a test spectrum of AM 1.5G. Since test labs typically do not have the capability to measure precisely at this reference spectrum, a spectral mismatch correction factor (MM) is used. Procedures for calculation and application of the MM are documented in IEC 60904-7. Furthermore, the uncertainty of the MM has been researched elsewhere in the literature [1] and [2].

The Department of Photonics Engineering at Denmark's Technical University (DTU) uses an EcoProgetti EcoSun10L for PV module characterization. This solar simulator has a 1.2m x 2.0m test area that is illuminated by 77 LED boards. Each board contains an array of LEDs consisting of 12 different colors, 8 of which are addressable and can be configured by the operator.

The MM factor is derived as shown in (1) where $E_{ref}\lambda$ is the AM 1.5G reference spectrum. The EcoSun10L solar simulator is in theory capable of performing relative spectral response measurements by activating one LED channel at a time and measuring the photo-current output. This data would provide $S_{DUT}\lambda$, but we will use external quantum efficiency (eQE) measurements from the PV device under test (DUT) manufacturer instead as it contains more than 8 data points per curve as well as measurements > 950nm. The solar simulator spectrum is measured at the center of the test plane with an Avantes AvaSpec-2048 spectroradiometer (Fig. 1). Calibration of the spectroradiometer is performed on site with a Tungsten-Halogen reference lamp. The spectral measurements from the Avantes provide $E_{meas}\lambda$. Finally, $S_{ref}\lambda$ is the spectral response of the reference cell. For this variable we will use the eQE data for a calibrated mono-Silicon reference cell manufactured by ReRa and measured by PV Calibration Facility Nijmegen. The Isc values of these reference cells are mismatch corrected.

$$MM = \frac{\int E_{ref}(\lambda)S_{ref}(\lambda)d\lambda \int E_{meas}(\lambda)S_{DUT}(\lambda)d\lambda}{\int E_{meas}(\lambda)S_{ref}(\lambda)d\lambda \int E_{ref}(\lambda)S_{DUT}(\lambda)d\lambda} \quad (1)$$

The correction is applied by dividing the measured Isc (I_{sc_meas}) by the MM factor, which results in a spectrally corrected Isc (I_{sc_corr}). Note that the MM factor is equal to 1 when the test spectrum matches the reference spectrum or when the spectral response of the DUT matches that of the reference cell.

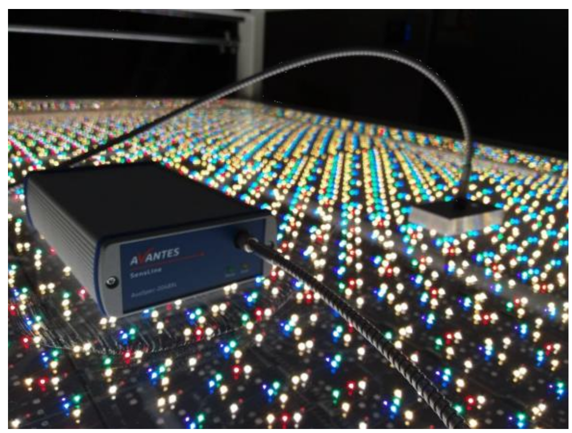

Figure 1: Measurement of the EcoSun10L spectrum with the Avantes Spectroradiometer.

We will use a second reference cell of similar characteristics as a DUT. The MM has been calculated for both cells using the Ecosun10L spectrum measured at our lab, and the difference is smaller than 0.7 %. We expect to increase this value by generating spectra of classes B and C.

II. Results

The emission spectra of the 8 configurable LED channels in the EcoSun10L are shown in Fig. 2. The emission of each channel is normalized to the peak value. The 8 channels consist of UV, blue, green, cool white, natural white and three channels for infra-red (IR) light. Each IR channel has 2 or 3 LEDs in series, which is why channels 6, 7 and 8 in Figure 2 have 2 or 3

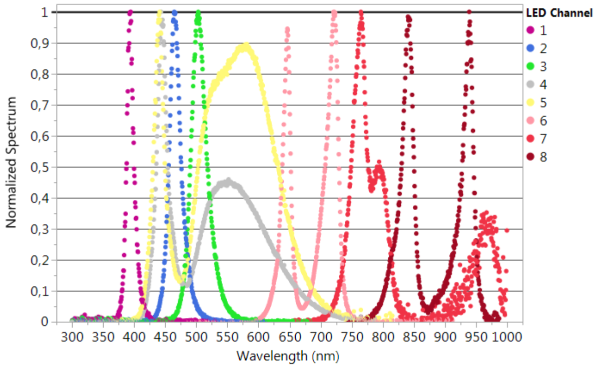

Figure 2 : Normalized emission spectra of the 8 LED channels within the EcoSun10L solar simulator.

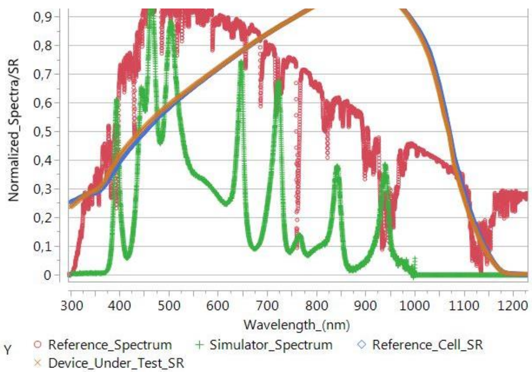

Figure 3: Overlay of the AM 1.5G reference spectrum, a class A spectrum measured in the EcoSun10L solar simulator, spectral response of the mono-Si reference cell and DUT.

emission peaks. The intensity of each channel can be individually adjusted to create a desired spectrum.

Fig. 3 shows an overlay of the AM 1.5G reference spectrum, the default EcoSun10L spectrum when all 8 LED channels are turned on, the mono-si DUT and reference cell. The EcoSun10L spectrum in Fig. 3 is configured for a class A spectral match.

IEC 60904-9 defines three solar simulator classifications for spectral match relative to the reference spectrum – class A, class B and class C. Fig. 4 shows how the distribution of the

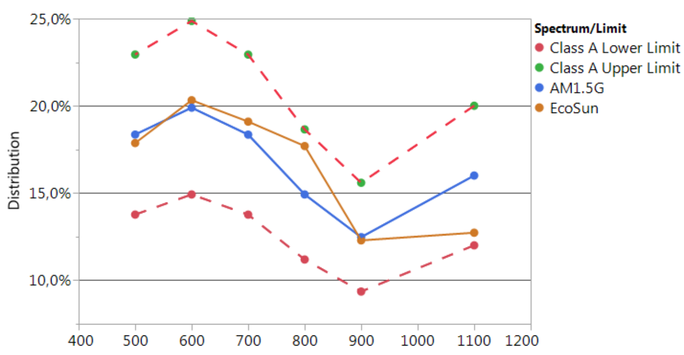

Figure 4: Spectral match of the default EcoSun10L class A spectrum

class A test spectrum matches that of the reference spectrum. In the final work, this plot will be improved as we will generate six unique test spectra, two spectra from each IEC class. We will perform Isc measurements on our DUTs under each test spectrum and apply the MM factor to each measurement to obtain I_{sc_corr}. Finally, we will analyze the introduced variation on the measurements under each test spectrum using a statistical process control (SPC) platform. These corrected measurements will be compared also with the calibration corrected values.

III. CONCLUSIONS

For the final poster, six unique class A, B and C test spectra will be generated with an LED-based solar simulator. Measurements will be performed on two monocrystalline reference cells with calibrated Isc value, one acting as a DUT. The Isc measurements will be corrected with a spectral mismatch correction factor. The accuracy of the correction will be quantified through SPC. Through this experiment we intend to validate if the spectral mismatch procedure can correct a PV measurement to the AM1.5G spectrum, irrespective of the test spectrum. Based on the results that are generated, we will be able to say to what extent the test spectra's similarity to AM1.5G is important. For example, if the I_{sc_corr} value is constant irrespective of class A, B or C spectra, we will be able to conclude that as long as one accurately knows what the test spectrum is, the spectral match is of secondary importance.

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